ANALYSIS OF THE LATERAL RESPONSE OF A REINFORCED CONCRETE PILE PENETRATED IN SAND SOIL USING FINITE ELEMENT

Ameer A. Jebur [1,] , William. Atherton [1], Rafid M. AL khaddar [1], Edward. Loffill [1]
[1]Liverpool John Moores University, Faculty of Engineering and Technology, Department of Civil Engineering, Peter Jost Enterprise Centre, Byrom Street, L3 3AF ,Liverpool, UK.

Email: A.A.Jebur@2015.ljmu.ac.uk; W.Atherton@ljmu.ac.uk; R.M.Alkhaddar@ljmu.ac.uk; E.Loffill@ljmu.ac.uk

A B S T R A C T

Pile foundations are slender elements, underneath a major structure, frequently used for many decades as load carrying and load transferring systems from shallow inadequate subsurface soil layers to deep and stiff bearing strata with high degree of efficiency. Moreover, the laterally loaded response of concrete reinforced piles penetrated in sandy soil is normally analysed using Winkler Model (beam on elastic foundation), in which the sand-pile-sand interaction is simulated by highly nonlinear *p–y* curves. The present study presents the result of numerical analyses of the behaviour of reinforced concrete squared model piles (400 mm in diameter) with embedment depth-to-diameter ratio (*L/d*) of (20)penetrated in a calibrated chamber of pre prepared dense sand relative density $(D_r\%)$. The model piles subjected under lateral loading system. The study revealed that the sand specimen shear strength parameters and the model pile dimension are the most significant parameters influencing the pile behaviour and its capacity

KEY WORDS: Reinforced Concrete Pile; Slenderness Ratio; Soil-Pile Interaction; Winkler Model; Shear Strength Parameters.

1. INTRODUCTION

Pile foundations are slender elements, underneath superstructures, frequently used for many decades as load carrying elements, (Miyasaka et al., 2008; Manandhar and Yasufuku, 2013; Karim et al., 2014; Alkroosh et al., 2015; Jebur et al., 2016) . Illustrations of major structures where the utilise of pile foundations are sky scrapers, bridges, transmission towers ,offshore platforms, jetties and geotechnical structures. These superstructures should be designed to resist moments and lateral loads of wind waves and earthquakes. Moreover, there are some geotechnical structures such as, oil production platforms, earth retaining structures, and deep open excavations where the role of piles is to resist and transfer lateral applied loads to the deep strata (Ensoft, 2005; Fellenius and Tech, 2008; Elhakim et al., 2014; Ebrahimian et al., 2015; Faizi et al., 2015). Salgado (2008) reported that the whole or a part of the deep foundation might be laterally moved when it is under a lateral load, as a consequence, rotation and/or bending moments will be induced in the structural element. The precise prediction of the soil-pile interaction is a typical problem in a laterally loaded pile foundation . However, it is necessary for geotechnical engineers to bear in mind in terms of pile design and analysis to determine the stresses-strain distribution and the deflections that are generated in a structural element and the contacting mass specimen in the lateral effective zone. the model of the Beam-on-Winkler-Elastic-Foundation (which is often so-called the ‘‘*p–y*’’ behaviour), is a precise method, in geotechnical engineering, to predict the response of horizontally loaded piles (Kim and Jeong, 2011); (Ni et al., 2014). The main concept of the Winkler model (1867) is to represent the soil layer with a series of unlimited numbers of elastic springs. It is noteworthy that the spring elasticity is the same as the soil subgrade reaction(k_h). Poulos (1971) was the first researcher who investigated and developed practical procedures for free and fixed head pile foundation under the action of lateral loading conditions . the researcher assumed that the contacted media is a plastic-elastic soil. In this research, finite element code (FEC) is optimised to analyse and simulate a laterally loaded reinforced concrete model pile. The lateral deflection of the pile, the soil-pile interaction, and the distribution profiles of shear and moment of soil with the depth were accurately determined.

2. THE NUMERICAL MODEL

In this paper, finite element code was used for running a series of models of soil-pile interaction. The main application of this novel method is the need for few input parameters that can be easily determined by conducting a short-term experimental test , as described in the next paragraphs. It is important to determine the input parameters precisely to calculate the sand-pile interface in the sand effective depth. To model the behaviour of the soil, an elastic-plastic approach is taken along with the application of Mohr-Coulomb failure criterion. A schematic diagram of the concept of the p-y curves for laterally and axially loaded piles, and the numerical model of the soil pile interaction are shown in Figures 1 and 2 respectively.

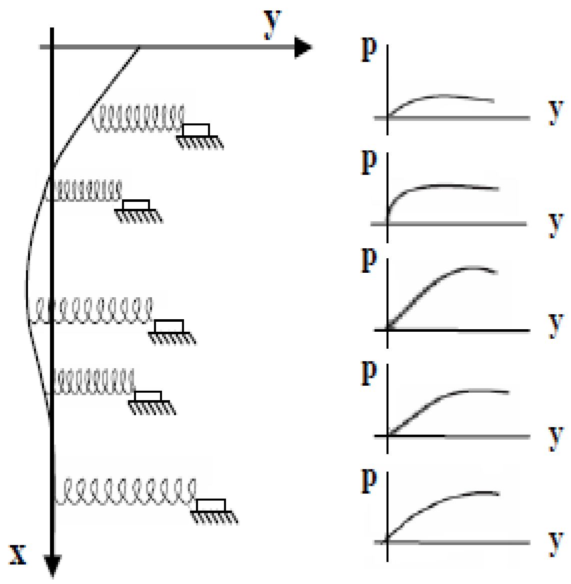


Figure 1: Soil- pile interaction of a pile model subjected via lateral loading according to the *p-y* curves approach, improved after (Ensoft, 2005).

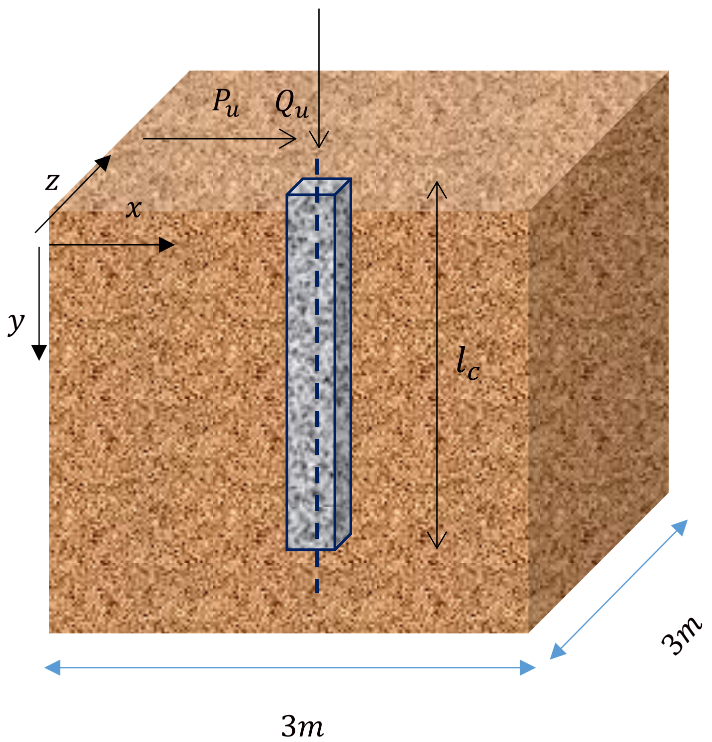


Figure 1: Model of the reinforced concrete pile subjected to combined loads

3. EXPERMENTAL WORKS

Few laboratory tests has been conducted on adopted sand media. According to the procedure of the unified soil classification system (USCS), the sand specimen used in this study can be classified as a SP. The sieve analysis test of the sand bed that has been adopted in the proposed model is shown in Figure 3., while the result of the direct shear test is presented in Figure 4. the scanning electronic microscopy (SEM) for the sand sample, Figure 5, shows that the shape of sand grains is sub-rounded. The main physical and chemical properties are attached in the Table, 1.

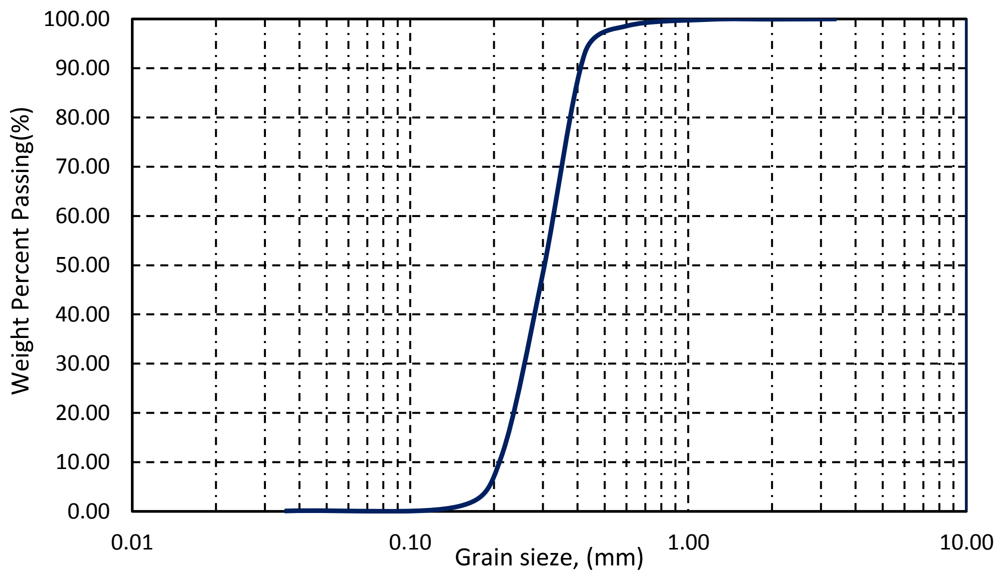


Figure 3: Sand specimen particle size distribution.

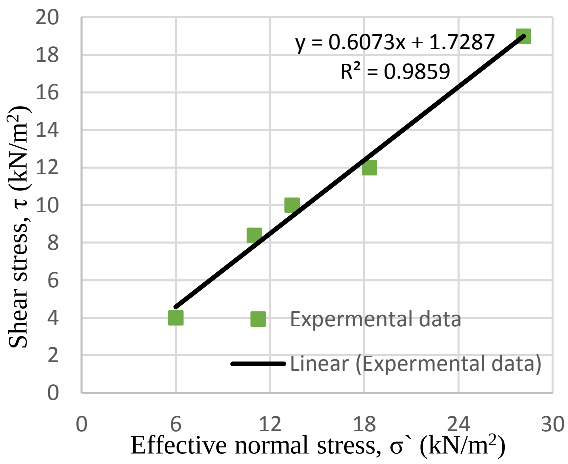


Figure 4: Sand-sand direct shear box test results

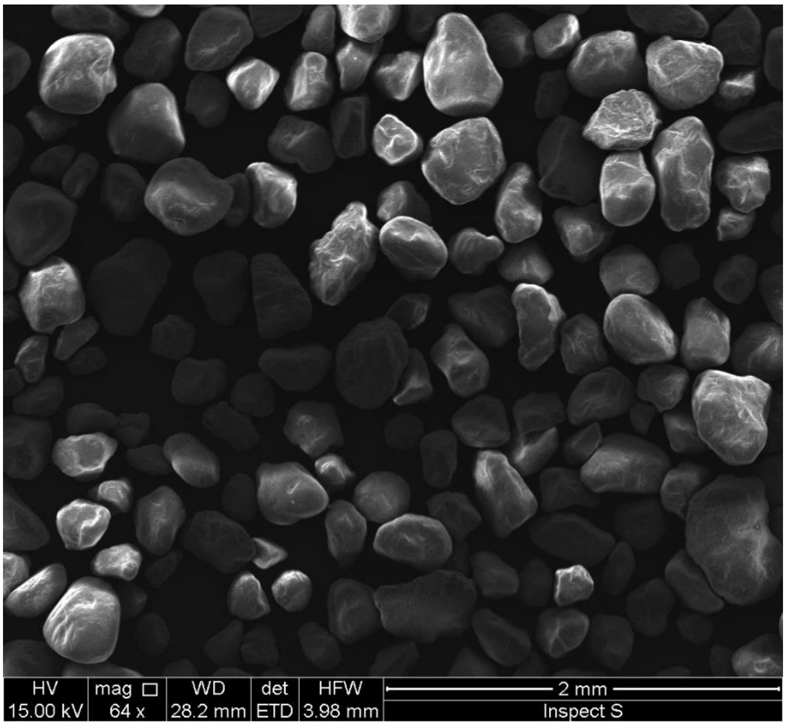


Figure 5: Scanning electronic microscopy, SEM

Table 1: Properties of the sand model input parameters.

Soil Property	Value	ASTM
Coefficient of Uniformity, Cu	1.40	D 2487
Specific Gravity, G_S	2.66	D 891
Coefficient of Curvature, Cc	0.92	D 6913
Effective Grain Size, D_{10} (mm)	0.20	D 6913
Moisture Content, Mc (%)	< 0.3 %	D 1558
Specific Surface Area, (cm^2/ml)	946.3	C 1069
Maximum Dry Unit Weight, $\gamma_{d\,max}$ (kN/m^3)	19.10	D 7382
Minimum Dry Unit Weight, $\gamma_{d\,min}$ (kN/m^3)	14.00	D 7382
pH	5.4	D 1293
Sand Classification, (USCS)	SP	D 2487
Silicon dioxide, SiO2	> 96%	C 114
Aluminium oxide, Al2O3	Max 2%	C 114
Sodium oxide, Na2O	0.32%	C 114
Calcium oxide, CaO	0.87%	C 114
Ferric oxide, Fe2O3	0.27%	C 114
Potassium oxide ,K2O	0.85%	C 114
Magnesium oxide, MgO	0.23%	C 114
Loss of ignition, LOI (%)	0.21	C 114
Angle of internal friction, φ	37.5^0	D 7891
Soil-pile interface friction, δ	26.0^0	D 7891

4. LAODING STATUS

A rectangular reinforced concrete model pile is adopted in this numerical modelling process, considering slenderness ratio (lc/d) for the response simulation of long/rigid piles, Table 2. During the numerical analysis, the static lateral loads were applied at the end of the concrete pile,a free additional length of 20 mm was made to overcome the temporary contact between the applied load and soil surface. Additionally, to avoid the boundary effect of the soil container walls Robinsky and Morrison (1964) have stressed that the minimum influence zone of the sand container varies between 3-5 times pile diameters(which is 400 mm in the present research) depending on soil stress history and the method of pile advancing. In the present research, the extent of the sand bed is up to10 times the pile diameter from the centre of the test pile. The concrete pile material properties were approved from (Gere and Timoshenko, 1997).

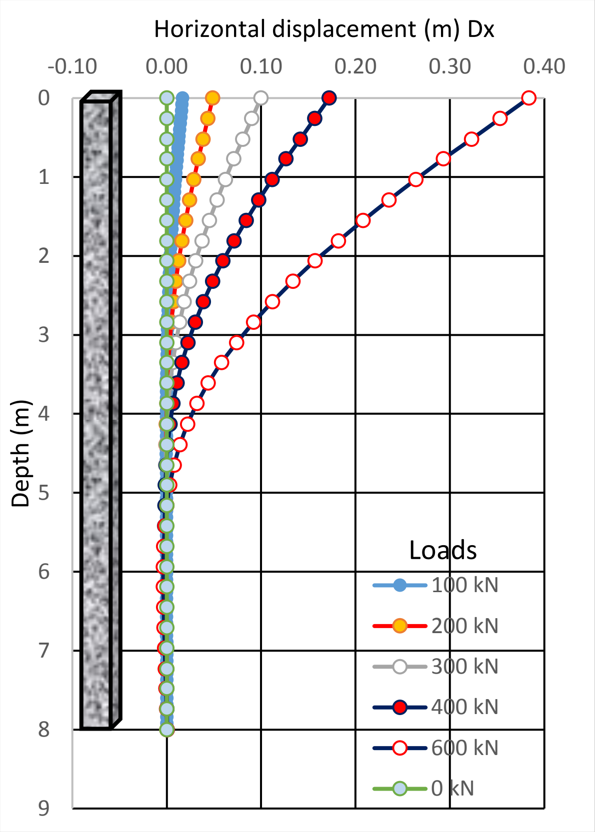
Table 2: Properties of the model input parameters for the proposed pile model.

Test ID	Poisson's Ratio, υ	Applied Loads, kN	Sand Mass Relative Density, Dr %	Modulus of Elasticity, Ec, MPa	Test Depth (cm)
T SC1-1	0.2	0	72	24,000	800
T SC1-2	0.2	100	72	24,000	800
T SC1-3	0.2	200	72	24,000	800
T SC1-4	0.2	300	72	24,000	800
T SC1-5	0.2	400	72	24,000	800
T SC1-6	0.2	600	72	24,000	800

5. RESULTS AND DISCUSSION

The results of the numerical modelling of the sand-pile-sand interaction under laterally loading conditions . , the resistance of the ground (sand), load-displacement curve, shear force profile, and a consequence moment distribution are shown in Figures 6 and 7. it can be seen from these figures that the soil-pile interaction is highly non-linear.

The results of the numerical analysis for the influence of shear forces profiles on model pile head deflection is illustrated in Figure 6. It can be seen that the maximum pile head deflection for a rigid model pile having slenderness' ratio (l/d = 20) is about 38cm for 600$\dot{K}n$ lateral load . In addition, for the pile head deflection subjected to 400$\dot{K}n$ is about 0.18cm. On the contrary, just 5cm and 2cm deflections have been noticed, in the direction of the applied load, for a lateral load of 200 $\dot{K}n$ and 100$\dot{K}n$ respectively. It can be seen that for all applied loads, the model piles start to bent at about 4m depth from the direction of the applied loads. Regarding the shear profile, it can be noticed that the maximum shear was about -620$\dot{K}n$ as a result of applying 600 $\dot{K}n$ load. While, the shear distributions for the rest of the applied loads decreased significantly from -400$\dot{K}n$ to about -100$\dot{K}n$ for applied loads ranged from 400 to 100 $\dot{K}n$ respectively.



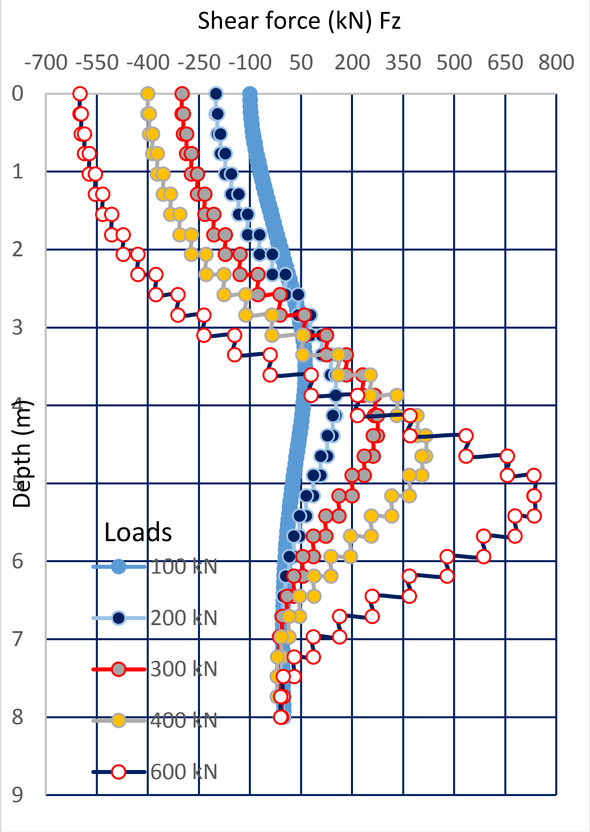


Figure 6: Displacement versus pile depth. **Figure 7: Shear force versus pile depth.**

The profile of the moment and the net ground reaction within the sand depth for the reinforced concrete pile are presented inFigure 8. The maximum moment convinced in a reinforced concrete model pile is about 1500Nm under 600$\dot{K}n$ at a sand depth of about 3.8m, Figure 8. while for 400$\dot{K}n$ applied load, the maximum moment took place at depth of about 880Nm at a depth of about 3m in the effective penetrated zone. Additionally, the moment induced for the 300$\dot{K}n$ and 200$\dot{K}n$ the moment profiles are 560Nm and 300Nm respectively. The moment occurred for the applied load of100$\dot{K}n$ is just 90Nm. Moreover, the net ground reaction profile against the distribution of the model pile-soil interaction depth is presented in Figure 9. As illustrated, the maximum ground resistance is about 650 $\dot{K}n/m^2$ induced at depth of about 4.3m from the point of the applied load. For both 400$\dot{K}n$and 300$\dot{K}n$ the ground resistance are 400$\dot{K}n/m^2$ and 280$\dot{K}n/m^2$occurred at depths of 3.2m and 2.7m respectively. the net ground reaction reached value of about 125$\dot{K}n/m^2$and 70$\dot{K}n/m^2$for the applied loads of 200$\dot{K}n$and 100$\dot{K}n$ respectively. in the reverse direction of the lateral load along lower zone of the effective profile depth, the peak ground resistance occurred at depth of about 6.2m reached a value of about -450$\dot{K}n/m^2$.

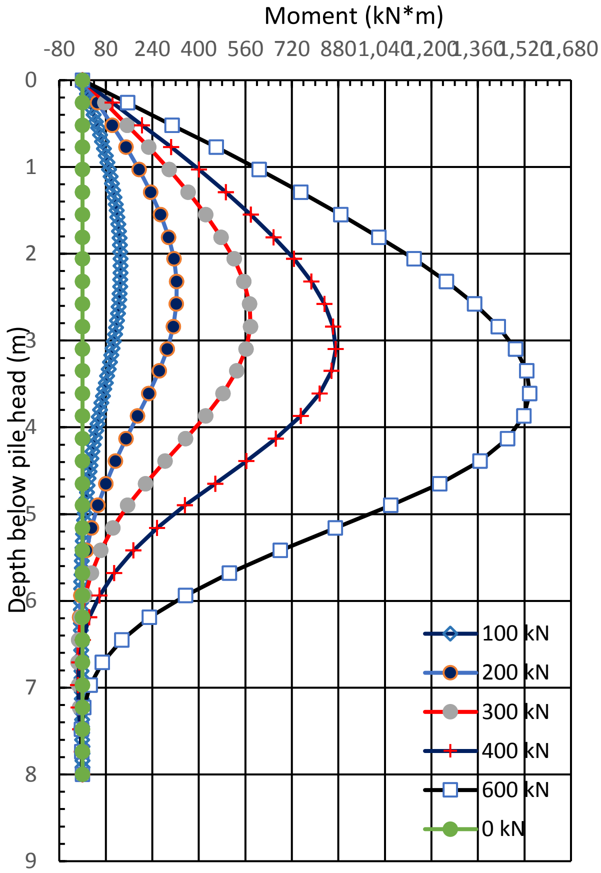


Figure 8: Moment versus pile depth.

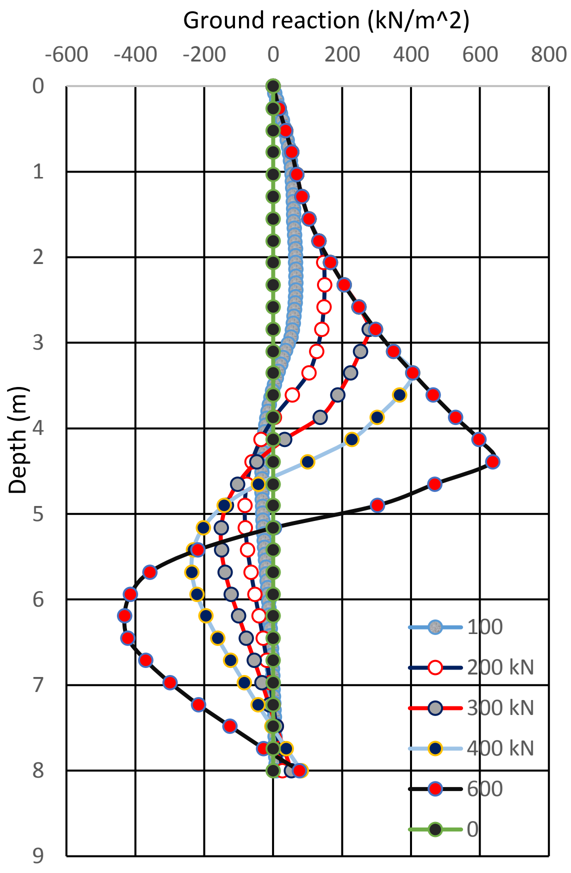


Figure 9: Ground reactions versus pile depth.

CONCLUSION

A finite element code has been developed and optimized to simulate the sand-pile-sand interaction by means of numerical modelling, this modelhas the ability to predict the high non-linearly between the soil-pile interaction. The model pile that has been adopted in this research is a reinforced concrete pile with dimensions of (0.4 * 0.4)m with 8m long. The lateral applied loads were change from (0, to 100, 200, 300, 400 and 600)$\dot{K}n$. Furthermore, the pile penetrated in a properly scaled down chamber to avoid the stress-strain distribution issues. The proposed method of analysis ,in this research, takes advantage of a proper constitutive numerical model for the major influence input parameters that affect the analysis such as, the properties of the sand specimen and the model reinforced concrete piles. The results of the numerical model show good agreements with that of other researcher in the literature. Generally, the effective profiles of the model pile-soil interface shear forces, bending moments and ground reactions were occurred at soil depth of around 4m from the point of the applied load. furthermore, the forces induced from the lateral independent horizontal load are a function of the lateral earth pressure coefficient (k), slenderness ratio (lc/d, and the sand mass relative density ($D_r\%$). Moreover, it was noticed that at specific certain depth "$critical\ pile\ depth$" the increment values in the moment distribution, shear profile, and pile head deflection start to be marginally changed. The critical depth for studied model pile and sand bed is determined to be about 5m.

ACKNOWLEDGEMENTS

The first author would like to express his gratitude to Dr. William Atherton and Prof. Rafid AL khaddar for their help and support during this research.

REFERNCES

Alkroosh, I. S., Bahadori, M., Nikraz, H. & Bahadori, A. 2015. Regressive Approach for Predicting Bearing Capacity of Bored Piles From Cone Penetration Test Data. *Journal of Rock Mechanics and Geotechnical Engineering***,** pp. 584-592.

American Society for Testing and Materials Specifications 2012.

Ebrahimian, B., Nazari, A. & Pasha, A. Y. 2015. Evaluating of the lateral load–displacement behavior of piles in clay. *Ocean Engineering,* 96**,** pp. 149-160.

Elhakim, A. F., El Khouly, M. a. A. & Awad, R. 2014. Three dimensional modeling of laterally loaded pile groups resting in sand. *HBRC Journal*.

Ensoft, I. 2005. LPILE Plus 5.0. Ensoft, Inc.

Faizi, K., Jahed Armaghani, D., Sohaei, H., Rashid, A. S. A. & Nazir, R. 2015. Deformation model of sand around short piles under pullout test. *Measurement,* 63**,** pp. 110-119.

Fellenius, B. H. & Tech, P. 2008. Effective stress analysis and set-up for shaft capacity of piles in clay. *The Geo-Institute of the American Society of Civil Engineers,* **,** 384 - 406.

Gere, J. M. & Timoshenko, S. P. 1997. Mechanics of materials xvi, 912 p. 4th eddition

Jebur, A. A., Atherton, W., Alkhaddar, R. M. & Loffil, E. 2016. Deep Foundations: Analysis of The Lateral Response of Closed Ended Steel Tubular Piles Embedded In Sandy Soil Using p-y Curves. *The fifteenth Asphalt, Pavement Engineering and Infrastructure Conference, Liverpool John Moores University, Vol 15. ISBN 978-0-9571804-8-2, UK.* **,** pp. 1-9.

Karim, M. R., Lo, S. C. R. & Gnanendran, C. T. 2014. Behaviour of piles subjected to passive loading due to embankment construction. *Canadian Geotechnical Journal,* 51**,** 303-310.

Kim, Y. & Jeong, S. 2011. Analysis of soil resistance on laterally loaded piles based on 3D soil–pile interaction. *Comput Geotech***,** pp. 38:248–57.

Manandhar, S. & Yasufuku, N. 2013. Vertical bearing capacity of tapered piles in sands using cavity expansion theory. *Soils and Foundations,* 53**,** 853-867.

Miyasaka, T., Kuwabara, F., Likins, G. & Rausche, F. 2008. Rapid load test on high bearing capacity piles. *Science, Technology and Practice, Jaime Alberto dos Santos***,** pp. 501-506.

Ni, S.-H., Xiao, X. & Yang, Y.-Z. 2014. A P-Y Curve-Based Approach To Analyze Pile Behavior In Liquefied Sand Under Different Stress States. *Journal of GeoEngineering, Vol. 9. No 13***,** pp. 85-93.

Poulos, H. G. 1971. Behaviour of laterally loaded piles: I – single piles. . *J Soil Mech Found Div ASCE* 97(SM5):711–31.

Robinsky, E. I. & Morrison, C. F. 1964. Sand displacement and compaction around model friction piles. *Canadian Geotechnical Journal* 1 (2), pp. 81–93.

Salgado, R. 2008. *The engineering of foundations.*, The McGraw-Hill Companies, Inc.